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Investigation of Geomagnetic Field Forecasting
and Fluid Dynamics of the Core

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1. Problems: None

2. Approach

a. Conventional Kinematic Geomagnetic Forecast Models for Epoch 1980

Task a of this contract calls for the construction of two conventional kinematic geomagnetic forecast models for epoch 1980, based on pre-MAGSAT data. The two models selected for this purpose are the definitive model of Barraclough, Harwood, Leaton and Malin (1978), designated herein as IGS 65, and the model of Cain, Hendricks, Langel, and Hudson (1967), designated as GSFC 12/66. The first of these draws on data from the period 1955 to 1973 and gives main field and secular variation coefficients for epoch 1965 to order and degree N = 8. The second model is based on data from the period 1900 to 1966 and includes Gauss coefficients of the main field, secular variation and secular acceleration for epoch 1960, to order and degree N = 10. These two models were selected as among the best pre-MAGSAT models, based in part on their successfully tested ability to predict the radius of earth's core-mantle boundary magnetically, when compared with appropriate models of MAGSAT data (Voorhies & Benton, 1982).

We have used all of the available coefficients for the main field and time variations in these models to forecast the main field coefficients forward in time to epoch 1980 by straightforward expansion in Taylor series. We intend to include the resulting tables of these kinematic forecast coefficients in the final report.

It is known that, generally, magnetic models tend to deteriorate in accuracy rather rapidly when they are extrapolated outside the time interval during which the model is constrained by observations. For IGS 65 there was a 7 year extrapolation (from 1973 to 1980) but for GSFC 12/66 the extrapolation is over the 14 year interval from 1966 to 1980. It must be expected then that the IGS 65 model would give the better kinematic forecast at 1980. The following approach to test this supposition has been developed and implemented. MAGSAT data for epoch 1980 (more accurately 1979.85) were re-fit to the same fitting levels as in IGS 65 and GSFC 12/66 (Benton, Estes, Langel, and Muth, 1982). Then the difference between these re-fitted MAGSAT models (designated MGSTRF) and the pre-MAGSAT models was formed and contoured at earth's surface to reveal the locations and magnitudes of the discrepancies. The main results are described under Accomplishments. We regard Task a as essentially complete.

b. Evaluation of Magnetic Model GSFC 9/80

An approach has been developed and partially implemented for evaluating one aspect of the quality of the new geomagnetic model designated GSFC 9/80 (Langel, Estes, and Mead, 1981). This sort of work was not explicitly contemplated at the time this MAGSAT investigation was planned, but it is, nonetheless, thought to be worth doing as part of this project.

The work described by Voorhies and Benton (1982) strengthens our belief that, in the short run (i.e. on the time scale of decades), earth's core moves like a perfect conductor while the mantle can simultaneously be treated as a perfect insulator. That physics implies that the magnetic flux crossing each patch of area on the core-mantle boundary bounded by a zero contour of vertical magnetic field should be a constant of motion. By simple addition, so is the total unsigned magnetic flux crossing the entire core-mantle boundary. This provides a criterion against which to test geomagnetic main field and secular variation models. As elaborated below under Accomplishments, we have completed a set of computations of flux through patches for both the IGS 65 model and the GSFC 9/80 model; we find that the GSFC 9/80 model conserves flux, both patchwise and in toto, substantially better than does IGS 65.

Another basis for evaluating a model is to ask how accurately it locates, magnetically, the core-mantle boundary, whose radius is, of course, very well-known from seismology. In Voorhies and Benton, 1982 this question was answered for GSFC 12/66 and IGS 65 by comparing each of them with an appropriate (i.e. consistent) MAGSAT model. We have now used the main field, secular variation, and secular acceleration of GSFC 9/80 alone and found the core radius magnetically to an accuracy better than that obtained by Voorhies and Benton (see elaboration below).

3. Accomplishments

a. Conventional Kinematic Geomagnetic Forecast Models

Six important contour maps have been produced to help determine just how inadequate is our ability to forecast geomagnetic time evolution a decade or so into the future. The first set of three maps plots contours (for a truncation level $N_T = 10$) of $\Delta B_r, \Delta B_\theta, \Delta B_\phi$ at earth's surface where, for example,

$$\Delta B_r \equiv B_r\big|_{MGSTRF} - B_r\big|_{GSFC\ 12/66}$$

and the re-fit to MAGSAT data is for a fitting level $N_F = 10$, so as to be consistent with GSFC 12/66. The epoch of MGSTRF is 1979.85 and that of GSFC 12/66 has been brought forward to 1980. Maximum differences are two negative cells, located beneath the Indian Ocean and of magnitude 2396 and 2144 nT. Thus, although GSFC 12/66 does a good job over the 30 year interval 1930-1960 of determining the radius of earth's core-mantle boundary when compared to MAGSAT models for 1980, it makes errors of over 2,000 nT, compared to MAGSAT, when extrapolated 14 years beyond the end of the interval constrained by data. Maximum values of $|\Delta B_\theta|$, $|\Delta B_\phi|$ are comparable but somewhat smaller, 1510 nT and 1489 nT, respectively.

The other three contour maps are for the differences ΔB_r, ΔB_θ, ΔB_ϕ where now

$$\Delta B_r = B_r\big|_{MGSTRF} - B_r\big|_{IGS\ 65}.$$

Fitting and truncation levels are $N_F = N_T = 8$ and the epoch of MGSTRF is 1979.85, while IGS 65 has been brought forward to 1980. Maximum values of $|\Delta B_r|$, $|\Delta B_\theta|$, $|\Delta B_\phi|$ are, as expected, substantially smaller over the 7 year extrapolation from 1973 to 1980, namely, 661 nT, 420 nT, and 346 nT, respectively.

b. Evaluation of Magnetic Model GSFC 9/80

The results summarized in Figure 1 of the last Progress Report (#9) have also been obtained for the model IGS 65. Although not yet drafted into final form, it is apparent from the rough figure that total flux crossing the core-mantle boundary is not nearly so well conserved by this model as for GSFC 9/80.

Calculations of the magnetic flux through individual patches on the seismic core-mantle boundary bounded by null-flux curves have been completed for a truncation level of N=8. At that truncation level there are five magnetic equators (North polar, Pacific, Main, South American, African) so there are five independent flux conserving constraints that ought to be satisfied. For model IGS 65, for the five epochs 1955, 1960, 1965, 1970, 1975 we find deviation from constancy expressed as an overall percentage variation for the various patches as follows: North Polar (131%); Pacific (91%); Northern Magnetic Hemisphere (0.53%); South American (8.7%); African (9.6%). In contrast, for the model GSFC 9/80 for the five epochs 1960, 1965, 1970, 1975, 1980, we find: North Polar (86%); Pacific (15.7%); Northern Magnetic Hemisphere (0.35%); South American (2.5%); African (7.9%). In each case, GSFC 9/80 satisfies these frozen-flux constraints substantially better than does IGS 65.

To check on how well GSFC 9/80 determines the core radius, magnetically, a rather complete set of calculations has been made. The total absolute magnetic fluxes crossing the spheres of radius ratio r/a = 1, 0.9, 0.8, 0.7, 0.6, 0.58, 0.56, 0.54, 0.52, 0.50 have been calculated at epochs 1960, 1970, 1980 for the complete range of truncation levels from $N_T = 1$ through $N_T = 13$. The best value for core radius is achieved for $N_T = 8$ by finding the value of r at which the unsigned flux in 1980 was the same as at 1960. That value is 3463 km, only 22 km (or 0.63%) below the accurate seismic radius of 3485 km. Comparisons at shorter time separations (1960 to 1970, 1970 to 1980) give substantially poorer results (3215 km and 3670 km, respectively). We attribute this to dominance of round-off error from subtracting two large numbers which are not sufficiently different when the time interval is only 10 years.

4. Significant Results

A basis for evaluating geomagnetic models of the main field and its secular variation (plus higher time derivatives if they are part of the model) has been developed. One asks (a) how well does the complete model locate the core-mantle boundary magnetically, using the technique

of Hide (1978), and (b) how well does the model conserve magnetic flux crossing patches of area on the core-mantle boundary bounded by null-flux curves (Backus, 1968)? Calculations in progress strongly suggest that the recent geomagnetic model GSFC 9/80 for the 20 year period 1960-1980 is an extremely high quality model from this viewpoint. For example, when truncated to N=8, then back at the two extremes of its data interval (1960 and 1980), it conserves total absolute magnetic flux across the sphere of radius r=3463 km, which is only 22 km (or 0.63%) below the seismic core radius of 3485 km.

5. Publications: None

6. Recommendations: None

7. Data Utility: The modelling effort at GSFC is indispensable to this project and the data products received to date have been outstanding. The high quality found in the model GSFC 9/80 is, no doubt, due in part to the treatment of observatory anomalies, but also to the insertion of highly accurate MAGSAT data.